# IR Spectromicroscopy of Laser Irradiated Dental Hard Tissues

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## INTRODUCTION

Lasers are well suited for the modification and removal of dental hard tissue for the treatment of dental decay, to render the surface more resistant to acid dissolution and to prepare the surface for bonding to restorative materials. IR spectromicroscopy can be used to resolve thermally induced chemical changes in dental hard tissue as a result of laser irradiation in enamel, dentin and bone. Laser modified surfaces are typically rough requiring a high brightness IR source to acquire spectra of sufficient quality to resolve thermally induced changes in the mineral composition. Moreover, the high spatial resolution of synchrotron-radiation fourier transform infrared spectroscopy (SR-FTIR) enables spatial profiling of laser-ablation craters that are on the order of 200-300-$\mu$m in diameter and resolve changes in individual grains a few microns in diameter.

## METHODS

Human and bovine dental enamel was irradiated using three laser systems with pulse durations ranging from 3-ns to 200-$\mu$s. The pulsed carbon dioxide laser operating at a wavelength of 9.6-$\mu$m is primarily absorbed by the tooth mineral, the Er:YAG laser operating at 2.94-$\mu$m is absorbed by water, and the frequency tripled Nd:YAG laser operating at 355-nm is absorbed by the protein and lipid in the tooth. Two specific projects are described in this abstract. The first project focused the identification of the calcium phosphate phases that are formed during laser ablation, and the use of water to prevent the accumulation of non-apatite CaP phases on the irradiated surface during $CO_2$ and Er:YAG irradiation. Our recent studies have focused on the resolution of non-apatite calcium phosphate phases that have been deposited around the periphery of the ablation crater during the ablation event[1]. Such phases are likely formed in the high temperature plasma plume above the sample during ablation. The second project involved the selective removal of protein and lipid from the surface of dental enamel to increase the diffusion of chemical inhibitors of tooth decay such as fluoride for greater efficacy.

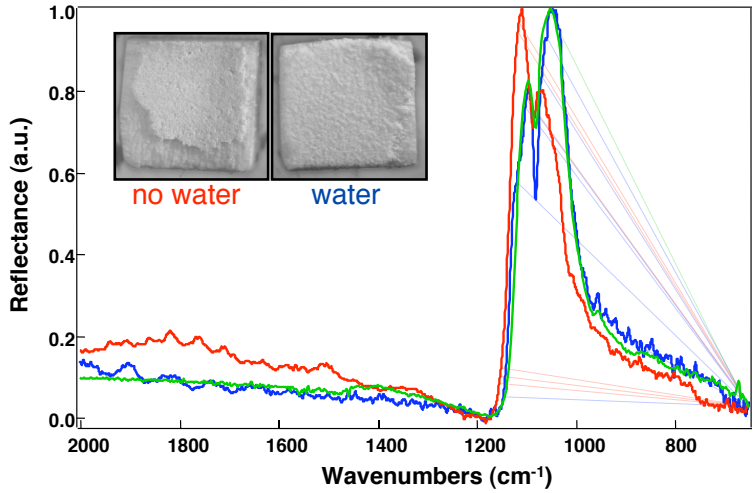


**Fig. 1.** *SR-FTIR spectra taken of areas of enamel irradiated without a layer of water (left image) and with a layer of water (right image) to prevent the formation of non-apatite CaP phases. Spectra shown are representative of (green) sound dental enamel, (blue) with the water layer and (red) without water.*

## RESULTS & DISCUSSION

*Spectra of Dental Enamel Irradiated with water-layer to prevent formation of non-apatite CaP phases*

Several studies have shown that the ablation of mineralized tissues by Er:YAG lasers is profoundly influenced by the addition of an optically thick layer of water. We postulate that

the recoil forces created during the interaction of the laser beam with the water layer prevent the accumulation of undesirable phases of CaP that reduce the rate and efficiency of ablation for subsequent laser pulses, adversely influence the bond strength to restorative materials and accelerate the rate of acid dissolution. After the optimum water delivery rate was determined to be 0.09 ml/min, surfaces of bovine enamel blocks were irradiated with and without water. Samples were irradiated at a fluence of 50 J/cm$^2$ with a spot diameter of 300 $\mu$m, a scan distance between spots of 50 $\mu$m, a pulse repetition rate of 3 Hz and 3 laser pulses per individual spot. SR-FTIR was used to acquire spectra from selected regions of the samples. In the regions of enamel irradiated by the laser with optimized water delivery, spectra of the enamel resembled that of either carbonated hydroxyapatite or pure-phase hydroxyapatite, the desired mineral phases. On the surface of samples irradiated by the Er:YAG without water present, Fig. 1, regions of melted and recrystallized mineral were present and the spectrum was significantly different from that of dental enamel suggesting either orientational changes in the crystal structure or the presence of non-apatite CaP phases. Further studies demonstrated that the modified enamel adversely effected the bond strength to composite restorations and by optimization of the water delivery rate undesirable phases could be removed to significantly increase the bond-strength[2].

*Selective Ablation of Protein/Lipid from Dental hard Tissue*

This study demonstrates that lasers can be used to selectively remove protein and lipid from the surface of dental enamel. A sheath of protein and lipid surround each crystal of carbonated hydroxyapatite that makes up the structure of dental enamel. We postulated that the protein plays a role in the diffusion of fluid into the tooth structure and can influence both the dissolution of the tooth mineral when exposed to organic acids and the inhibitory effect of topical fluoride. In order to test this hypothesis, we irradiated dental enamel at a laser wavelength that has the greatest potential of selectively removing the protein/lipid without markedly changing the composition of the mineral phase. Irradiation at IR laser wavelengths such as 9.6-$\mu$m result in thermal decomposition of the mineral phase, however 355-nm etches the protein/lipid without changes to the mineral. SR-FTIR spectra of areas of the bovine enamel etched by Q-switched 355-nm lasers pulses manifest no obvious chemical changes. In Fig. 2, three SR-FTIR of sound enamel, and enamel irradiated at 355-nm and 9.6-$\mu$m are displayed. Previous studies using carbon dioxide lasers have shown that pulsed and continuous laser irradiation results in melting and thermal decomposition of the mineral phase of enamel. This is most evident by a reduction in the 6.8 and the 7.1-$\mu$m carbonate ($CO_3^{2-}$) band intensities and changes in the intensity ratios of the three phosphate ($PO_4^{3-}$) bands between 9 and 11-$\mu$m. In Fig. 2, there are no differences between the intensities of the molecular absorption bands between sound enamel and enamel irradiated at 355-nm. Unfortunately, we cannot determine using SR-FTIR whether or not the protein and lipid is eliminated, because the small relative fraction of these species in enamel along with their nominal extinction coefficients preclude their measurement with SR-FTIR techniques. Further studies described confirmed that

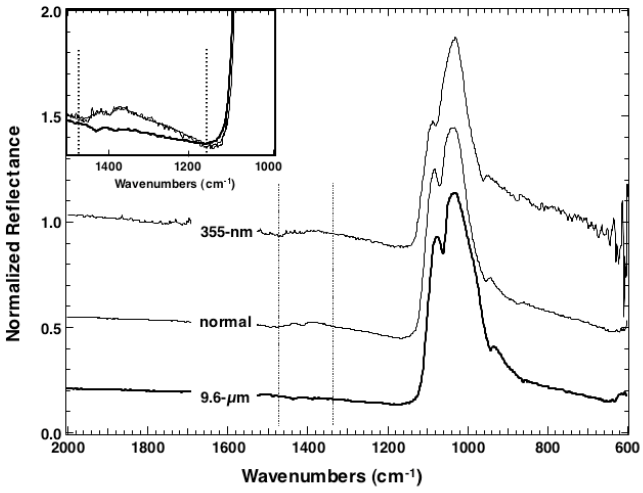


**Fig. 2.** *SR-FTIR spectra taken of areas of enamel irradiated by a 9.6-μm $CO_2$ laser and Q-switched 355-nm laser pulses. The spectrum of normal enamel is plotted for comparison. Temperature excursions in the enamel exceeding 300°C cause removal of carbonate, the two bands located between 1200 and 1400 cm$^{-1}$ (inset).*

the 355-nm laser pulses significantly increased the efficacy of topical fluoride delivery suggesting a novel method of caries inhibition and providing additional information about the mechanism of laser-induced inhibition of tooth decay[3].

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